

LONG-TERM TESTING OF HERMETIC ANODICALLY BONDED GLASS-SILICON PACKAGES

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ABSTRACT

This paper reviews long-term test results obtained from a series of tests on glass-Si hermetically sealed packages. Results are presented from: 1) a **6.7-year** ongoing room temperature phosphate buffered saline (PBS) soak test of 4 packages; 2) a **2.3-year** ongoing in-vitro 97°C PBS soak test of a single package; and 3) *in-situ* hermeticity and biocompatibility tests from 12 packages implanted in 4 guinea pigs - 3 packages implanted in each of 2 guinea pigs for 1-month and another 2 guinea pigs for **19-months**, and **22-months**. The long-term room temperature soak test is the *longest* running of any micropackage reported to date.

INTRODUCTION

Much attention has been focused on the development of miniaturized devices in the MEMS community. However, packaging of these miniaturized devices remains a particularly difficult problem. Many MEMS devices must function in harsh environments ranging from intense vibrations, corrosive fluids, and extreme temperatures with the added complication of *interfacing* the environment with delicate integrated sensors and actuators. A package intended for harsh media applications must maintain long-term hermeticity under these extreme environmental stresses. The package must

also have multiple feedthroughs to the outside world that do not compromise package hermeticity. It is also desirable to develop a package that is transparent to the portions of the electromagnetic spectrum to accommodate wireless devices.

An excellent example of devices that must be packaged and survive in harsh environments is in the area of implantable microdevices. The development of these microdevices has advanced considerably with the integration of micromachined devices and thin film electrodes. A few implantable microsystems have been reported: a urinary incontinence prosthesis [1], a spinal cord microstimulator [2], and various neuromuscular stimulators [3], [4], [5], [6]. A major challenge of developing these and other microsystems is proper hermetic packaging with feedthroughs to external sensors. These packages must maintain hermetic seals for long-term uses and demonstrate high reliability. To date many of these packages utilize titanium sealed packaging solutions proven in pacemaker technology. However, integrated circuit electrodes and other new integrated sensors require encapsulation that is less bulky [7], [8].

Long-term test results presented in this paper will show that the glass-Si package developed by our group is a possible solution to this particular implantable micropackaging challenge [9].

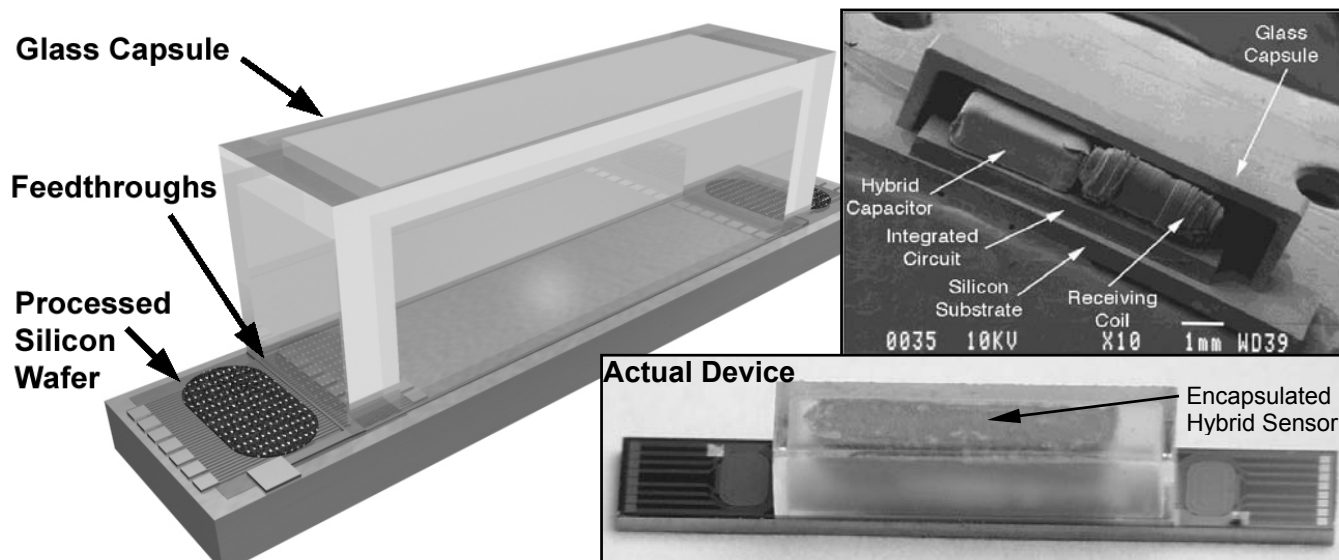


Figure 1 : Glass-Si package.

PACKAGE FABRICATION

Over the past few years, our group has developed a biocompatible hermetic package with high density multiple feedthroughs designed to withstand corrosive environments. This technology utilizes electrostatic bonding of a custom-made glass capsule to a silicon substrate to form a hermetically sealed cavity, as shown in Figure 1. Feedthrough lines are obtained by forming 5 μ m pitch polysilicon lines and planarizing them with LTO and PSG. The PSG is reflowed in steam at 1100°C for 2 hours to form a planarized surface. A passivation layer of oxide/nitride/oxide is then deposited on top to prevent direct exposure of PSG to moisture. A layer of fine-grain polysilicon (surface roughness 50Å rms) is deposited and doped to act as the bonding surface. Finally, a glass capsule is bonded to this top polysilicon layer by applying a voltage of 2000V between the two for 12 minutes at 320°C to 350°C, a temperature compatible with most hybrid components. The glass capsule can be either custom molded from Corning code #7740 glass, or can be batch fabricated using ultrasonic micromachining of #7740 glass wafers. The package cavity can encapsulate separate IC chips and off chip components as needed, also shown in Figure 1. The package incorporates integrated feedthroughs that are essential for interconnection to external sensors or actuators [9].

TESTING METHODOLOGY

In order to certify a package for use in a particular application it is important to qualify a series of tests consisting of: 1) accelerated tests to estimate mean-time-to-failure (MTTF), 2) control sample in unaccelerated environment tests to support the MTTF result, and 3) intended application environment (*in-situ*) tests to unveil any unexpected failure modes. We have chosen specific tests to qualify glass-Si packages in biological and other highly corrosive environments. Results presented in this paper focus on the *control* and *intended application in-situ* tests as highlighted in Figure 2.

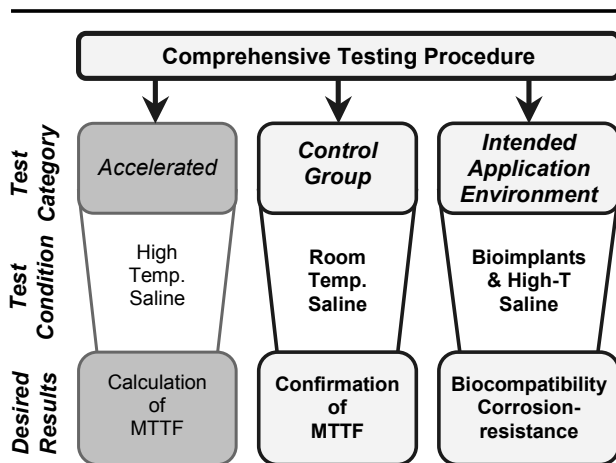


Figure 2 : A comprehensive package testing procedure.

LONG-TERM TESTING RESULTS

The following sections present long-term results from control group, accelerated, and intended application environment tests.

Control Group

The most significant results to date have been obtained from 6 packages soaking in phosphate buffered saline (PBS) solution for over 6.8-years at 23°C as summarized in Table 1. Capacitive dew point sensors within the packages are interrogated on a regular basis and the packages are visually inspected to monitor hermeticity. Other than one lost package due to mishandling and one lost due to failure in the first 24 hours, the remaining 4 packages are hermetic and have been soaking for 6.8-years and show no visible signs of corrosion. This room temperature soak test set is the *longest* running of any micropackage reported to date.

Accelerated

These room temperature saline soak tests supplement results obtained by our group from accelerated saline soak tests. We have performed tests on packages soaking in PBS at 95°C and 85°C to provide an accelerated test condition for biological environments. Using the Arrhenius relationship we have extrapolated a lifetime of 177-years at 37.5°C. A summary of these accelerated PBS soak test results are also listed in Table 1 [10].

Table 1 : Summary of saline soak test results.

| Temperature | 85°C | 95°C | 25°C |
|------------------------------|-----------|---------|-------------|
| # of Samples | 17 | 11 | 6 |
| Max #days survived in saline | 321-days | 70-days | 6.8-years |
| MTTF | 116-days | 38-days | None failed |
| MTTF @ 37°C | 177-years | | -- |

The only observed mechanism for failure of the glass-Si packages while soaking in high temperature PBS is the dissolution of the polysilicon layer used for anodic bonding. The polysilicon bond layer is dissolved, until a leakage path extends across the bond region of the package, thereby compromising the glass-silicon bond interface and causing failure. However, since the initiation of these accelerated and control group tests we have utilized techniques to further improve the lifetime and reliability of the packages. By using boron doping and/or galvanic biasing, we have shown that the dissolution of polysilicon can be reduced by several orders of magnitude [11].

Intended Application - High Temperature PBS

Additionally, a single glass-Si package, with an encapsulated passive wireless humidity sensor [12], has been soaking in PBS at 97°C for 2.3-years. The package is removed from the high temperature environment and brought to room temperature for wireless humidity monitoring and visual inspection. The humidity sensor data and visual inspection analysis strongly suggest the anodically sealed glass-Si package is hermetic. This particular package utilizes a galvanic bias etch stop to extend package MTTF by preventing the dissolution of the poly-Si layer. The plot in Figure 3 shows the percent relative humidity change versus the number of days soaking at 97°C. The sensor data along with visual inspection results strongly suggest the anodically-sealed package is hermetic after 2.4-years at 97°C.

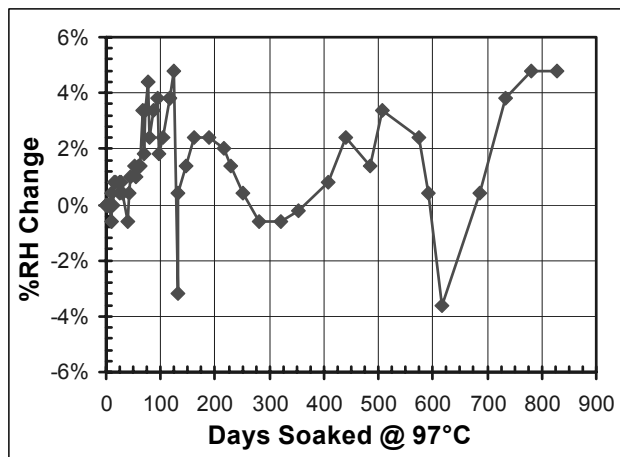


Figure 3 : Humidity monitoring data of package in 97°C PBS.

Intended Application - Bioimplants

Four guinea pigs have each been implanted with three packages for *in-situ* testing of both *hermeticity* and *biocompatibility*. Devices were implanted in the head beneath the skull above the dura, under the skin over the leg muscles, and in the abdominal cavity as shown in Figure 4.

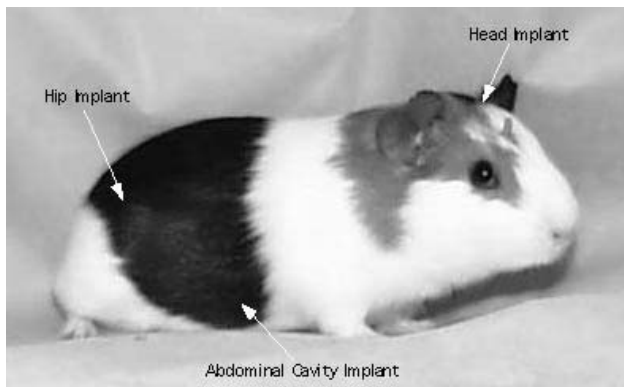


Figure 4 : Location of guinea pig implants

Two of the animals were implanted for 1-month each for short-term studies and tissue comparison with the long-term implants. Humidity inside the implanted packages in the remaining two guinea pigs were wirelessly monitored bi-weekly for 19-months and 22-months. Figure 5 shows the %RH change of three packages in one of the guinea pigs. The humidity within all six of the packages did not significantly change since its initial value at dry conditions, which indicates that the packages remained hermetically sealed for the lifetime of the implants.

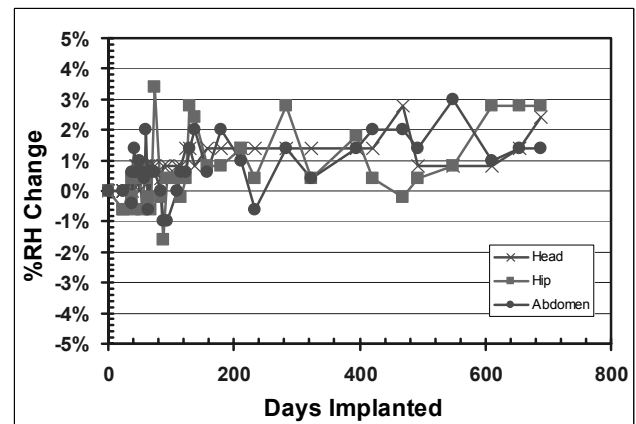


Figure 5 : %RH change measurements over time for 22-month guinea pig implants.

A plot of a wireless humidity sensor (HS) output before being packaged, average during the implanted period (hermetically sealed in dry condition), and after explant from the guinea pig and removal from the hermetically sealed package is shown in Figure 6. The humidity within the package did not significantly change since its initial value at dry conditions thus proving that the package maintained hermeticity. The pre-package and post-explant sensor responses do not match exactly because most likely because the sensor telemetry coil may have been slightly altered in the difficult process of breaking open the package to retrieve the sensor.

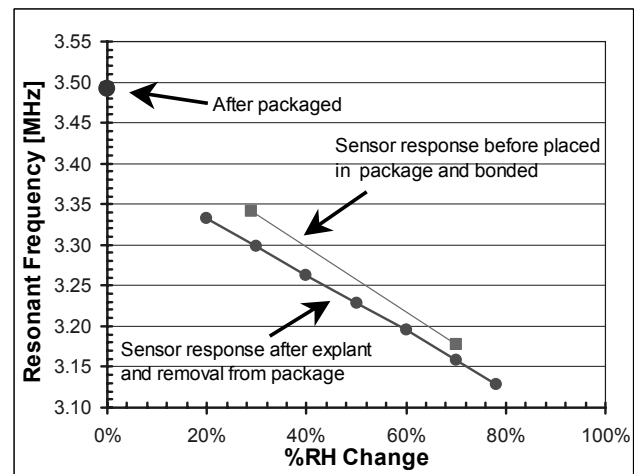


Figure 6 : Response from implanted wireless HS.

In addition to monitoring package hermeticity it is equally important to ensure that the biological host is not reacting adversely to the package geometry and materials. Therefore, we have conducted histological studies to ensure the long-term biocompatibility of the glass-Si packages. A summary of package hermeticity and biocompatibility tests, not monitored in-situ, are presented in Table 2 [10].

All biocompatibility studies, including those monitored *in-situ*, indicate that the devices remained hermetically sealed and that the tissues surrounding the glass-Si packages after explant are healthy.

Table 2: Summary of hermeticity and biocompatibility studies (bolded entries were monitored in-situ).

| | | | | | | | | |
|---------------------------|---|---|---|---|----|----------|-----------|-----------|
| # of implanted packages | 13 | 4 | 1 | 1 | 1 | 6 | 3 | 3 |
| # months implanted | 1 | 2 | 6 | 9 | 12 | 1 | 19 | 22 |
| Biocompatibility Comments | All packages remained hermetically sealed Healthy tissues surrounding the implants, packages are biocompatible, no sign of attack on package materials | | | | | | | |

CONCLUSION

Confirmation of hermeticity and biocompatibility proven by these long-term tests provide solid data demonstrating that these glass-Si packages are able to meet many of the demanding package requirements for use in highly corrosive environments. These micropackages will continue to be tested and updated.

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